# Satellite Synthetic Aperture Radar Detection of Ocean Internal Waves in the South China Sea

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Grant Number: N00014-05-1-0272

## LONG-TERM GOALS

The long-term goal of the project is to meet the goal of ONR DRI NLIW, which is to achieve the basic science understanding that leads to a predictive capability that will be able to tell when and where non-linear internal waves will occur and what effects they will have on the hydrodynamic and acoustic environment. This project focuses on the use of remotely sensed variables, together with models and in situ observation that can reproduce and predict the generation and structure of these waves, their evolution during propagation, and the processes controlling dissipation.

## OBJECTIVES

1). To determine the statistical features of ocean internal waves in SCS. Interpreting ten years of satellite synthetic aperture radar (SAR) images, the statistical features of ocean internal waves in SCS will be determined. 2). To understand the effects of topography/thermocline on the evolution of solitary internal waves in SCS. 3). To explore the SAR imaging conversion mechanisms of internal waves.

## APPROACH

Both in situ and remotely sensed data has been used in the analysis. For the remotely sensed data, the main source is the synthetic aperture radar (SAR) carried by various satellites, i.e., ERS-1/2, Radarsat-1/2 and Envisat. High resolution NOAA AVHRR data and SeaWifs, as well as data from Terra and Aqua satellites will also be used. Fore the insitu data, historical XBT/AXBT data are used to determine the vertical thermal structure in the study area. The data are obtained from NOAA archives, which are in the public domain. In addition, historical CTD data from NOAA-NODC as well as data from NLIWI program are used in collaboration with the PIs from observational team.

Two-dimensional Fourier transform is used to study wave number characteristics of internal waves. The HHT method developed by Huang et al. (1998) are used to determine the variation of spatial phase of internal waves and to trace back to their generation locations.

# Report Documentation Page

*Form Approved*
*OMB No. 0704-0188*



| 1. REPORT DATE | 2. REPORT TYPE | 3. DATES COVERED |
|---|---|---|
| **30 SEP 2008** | **Annual** | **00-00-2008 to 00-00-2008** |

| 4. TITLE AND SUBTITLE | 5a. CONTRACT NUMBER |
|---|---|
| **Satellite Synthetic Aperture Radar Detection Of Ocean Internal Waves In TheSouth China Sea** | 5b. GRANT NUMBER |
| | 5c. PROGRAM ELEMENT NUMBER |
| 6. AUTHOR(S) | 5d. PROJECT NUMBER |
| | 5e. TASK NUMBER |
| | 5f. WORK UNIT NUMBER |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Lamont Doherty Earth Observatory of Columbia University,Palisades,NY,10964-8000** | 8. PERFORMING ORGANIZATION REPORT NUMBER |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | 10. SPONSOR/MONITOR'S ACRONYM(S) |
| | 11. SPONSOR/MONITOR'S REPORT NUMBER(S) |

12. DISTRIBUTION/AVAILABILITY STATEMENT
**Approved for public release; distribution unlimited**

13. SUPPLEMENTARY NOTES
**code 1 only**

14. ABSTRACT
**The long-term goal of the project is to meet the goal of ONR DRI NLIW, which is to achieve the basic science understanding that leads to a predictive capability that will be able to tell when and where non-linear internal waves will occur and what effects they will have on the hydrodynamic and acoustic environment. This project focuses on the use of remotely sensed variables, together with models and in situ observation that can reproduce and predict the generation and structure of these waves, their evolution during propagation, and the processes controlling dissipation.**

15. SUBJECT TERMS

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT | b. ABSTRACT | c. THIS PAGE | | | |
| **unclassified** | **unclassified** | **unclassified** | **Same as Report (SAR)** | **6** | |

## WORK COMPLETED

**1).** The statistical analysis of IW occurrence in the northern South China Sea (NSCS) has been completed using seven years of satellite SAR images from 1995 to 2001.
**2).** Nonlinear analysis of effects of shoaling thermocline on the IW generation has been completed. The role of Kuroshio playing in IW generation in the Luzon Strait has been analyzed using linear wave models and the Fourier transform methods. Dynamical analysis of bottom-topography-induced stationary IW in NSCS has been completed.
**3).** Analysis of variability of thermocline depth in SCS has been completed. More than 37,000 CTD casts in the SCS are analyzed.

## RESULTS

1). Statistical analysis of seven years of satellite SAR images from 1995 to 2001, statistics of IW occurrence in NSCS generate the following results.:
   a. Figure 1 (updated from Zhao et al., 2004) shws statistical distribution of internal wave in north South China.
   b. Seasonal variability: April to July and reach a peak in June with a maximum frequency of 20%. The low occurrence frequencies are distributed in winter from December to February.
   c. Interannual variability: in1995, 1998, and 2000 where frequency are 2 to 5 times higher than that in other years. This interannual variability implies that there are long-term and large scale processes modifying the SAR-observed internal wave occurrence.
2). The thermocline shoaling provides the forcing to soliton amplitude growth, so that the soliton amplitude growth ratio.
3). Kuroshio plays role in internal wave generation in the Luzon Strait
4). Reflection coefficient associated with thermocline depth variability in the South China Sea based on historical CTD data (Figure 2) shows two large circulations in the SCS and also upwelling jet across the Vietnam coast. Characteristic of stratification along the internal waves propagation from Luzon Strait is shown in Figures 3 and 4. Further detailed analysis of all CTD data is needed.

## IMPACT/APPLICATIONS

The results of this project will provide the users a statistical outline of internal wave behavior and boundary conditions in SCS, and will benefit the broader oceanographic community, ocean engineering industries, underwater navigation and operational users. The results may also serve as a basis for empirical, theoretical, and numerical prediction models of internal wave behavior in SCS, and contribute to creation of a predictive system. The results will further reveal SAR imaging mechanisms and be used for SAR image interpretation.

## RELATED PROJECTS

- ✓ Ongoing ONR PO project titled “Analysis of Fine Structures of Flows, Hydrography, and Fronts in Taiwan Strait”. Quanan Zheng serves as a CO-PI. The study areas of two projects are immediately adjacent. Therefore, two projects sometimes share the same data resources of field observations.
- ✓ Ongoing multidisciplinary project supported by ONR-DRI to understand archipelago strait dynamics in the Mindoro Strait and adjacent straits within the Philippine region.

- ✓ Ongoing collaborative project (Indonesia-China-USA) to deploy an array of trawl- resistant, bottom mounted ADCP. Chinese PIs led by Prof. Guohong Fang of the First Institute Oceanography and US PI is Dr. Dwi Susanto and the Indonesian PI is led by Dr. Sugiarta (BRKP).
- ✓ Project supported by the ONR: N00014-04-1-0698; PI: Dwi Susanto on"An overview submeso-scale features in the Indonesian Seas has been completed. Some statistical and dynamical analyses have been applied to both Indonesian Seas and South China Seas; Hence we share authorships.

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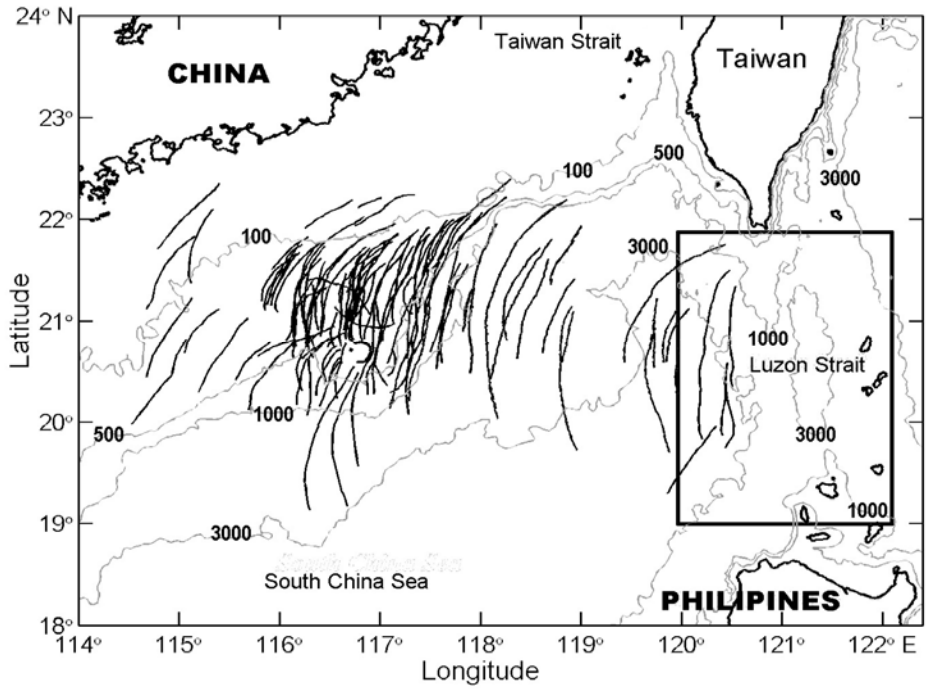
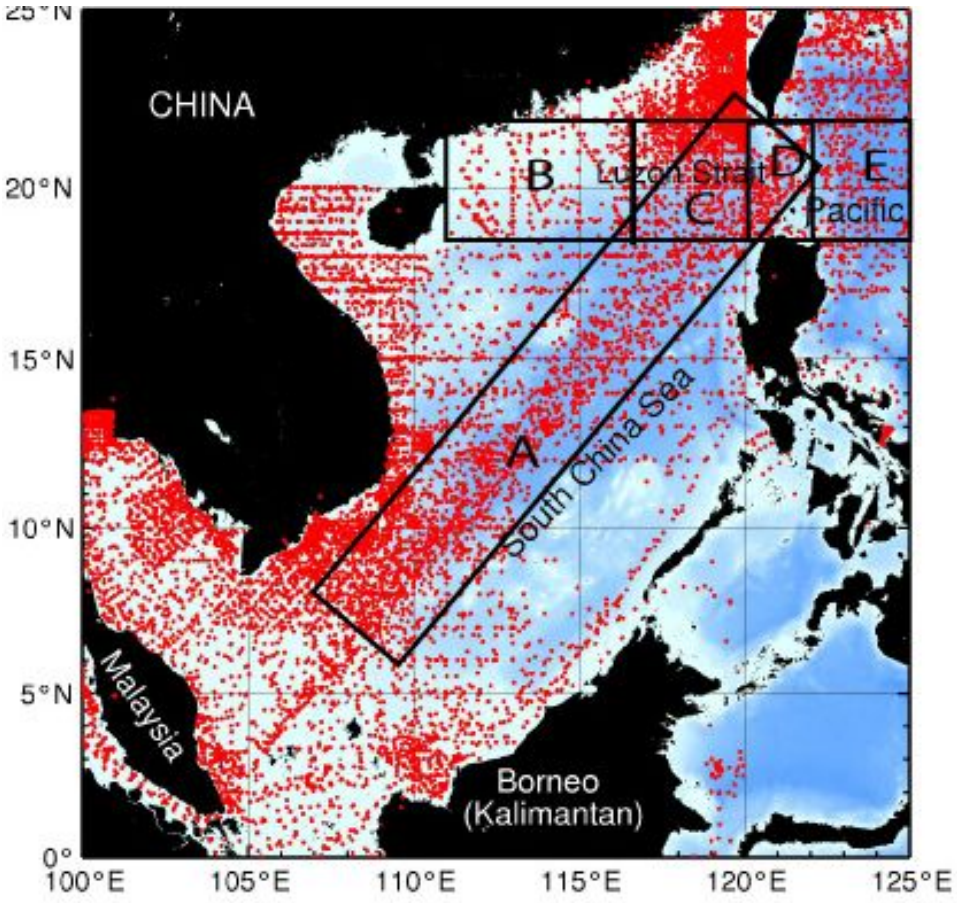
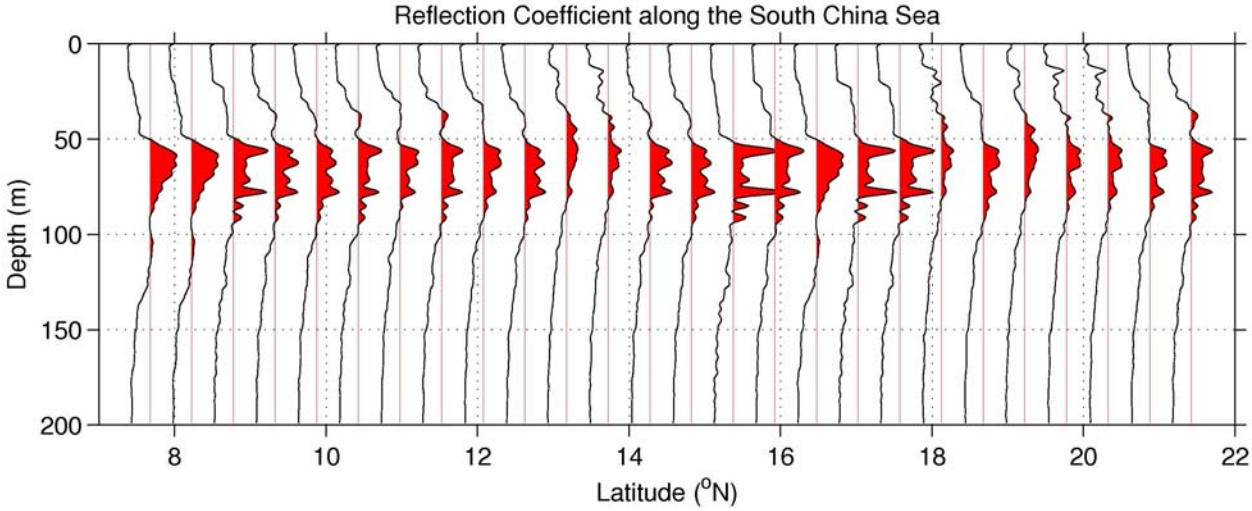


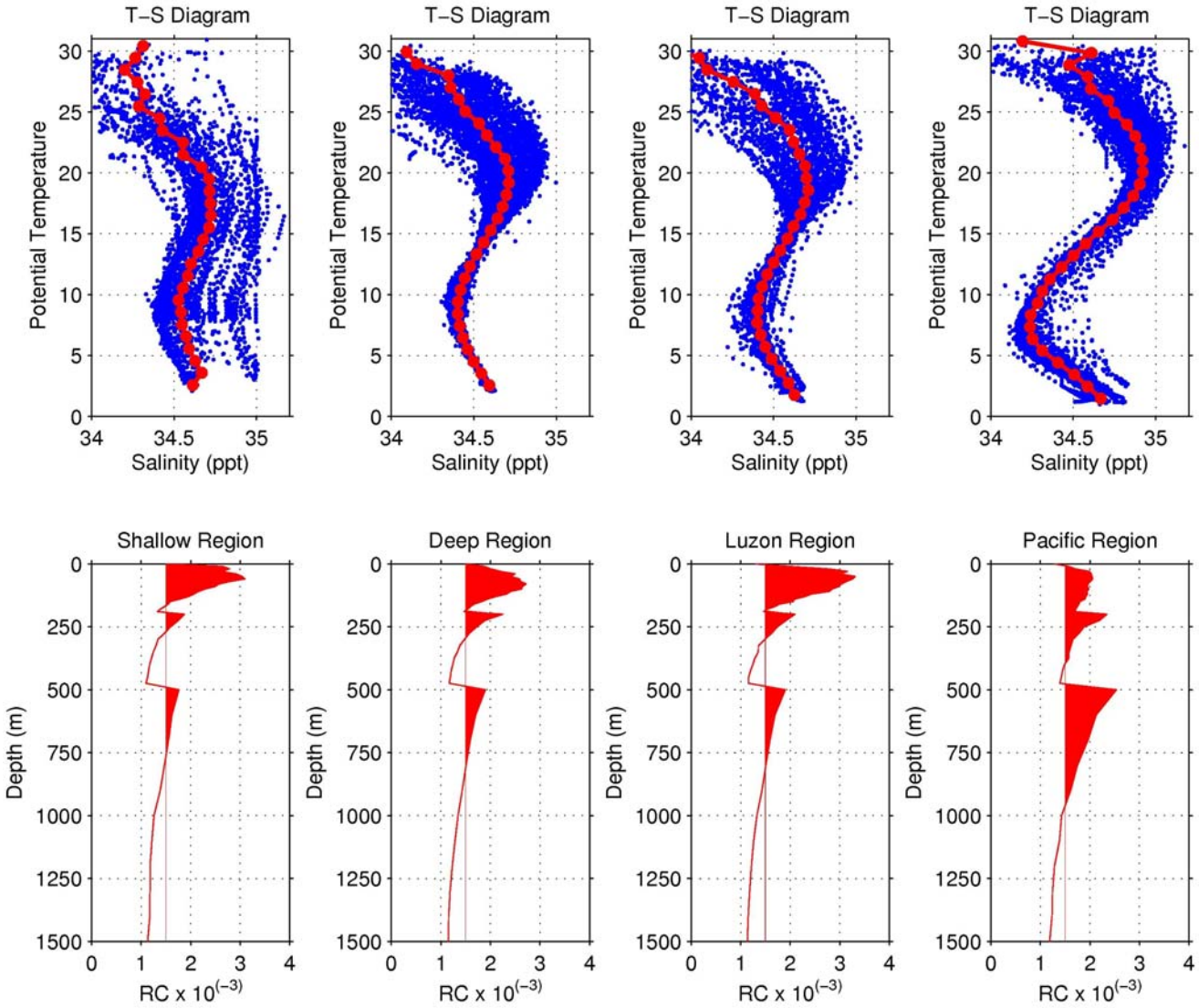

***[Figure 1. A map of latitudinal distribution of IW packets in NSCS. Bold lines represent crest lines of leading waves in IW packets interpreted from SAR images. The rectangular box on the right defines an IW generation source region for the dynamical analysis, Zheng et al., 2007.]***




*[Figure 2. Historical CTD data in the South China Sea used for analysis of thermclonice depth variability. Susanto & Zheng (in preparation)]*




*[Figure 3. Reflection coefficient associated with thermocline depth variability in the South China Sea (along box A). Susanto & Zheng (in preparation)]*




***[Figure 4. Characteristic of water stratification and its associated reflection coefficient along the internal wave propagations ( box E-D-C-B) in the South China Sea. Susanto & Zheng (in preparation)]***

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